"Readiness through Knowledge"

Headquarters Air Weather Service

Aerospace Sciences Division

Providing Service Worldwide

FYI

March 1997 Number 38

AIR WEATHER SERVICE

ICING

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When ice forms on an aircraft, it distorts the aerodynamic shape of lifting surfaces, resulting in degraded, if not total loss of aircraft control. Accurate icing forecasts are extremely important to each aircrew. This FYI is a refresher on icing and its effects on aviation, along with a review of icing analysis and forecasting techniques.

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Icing

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INTRODUCTION

Icing is responsible for numerous aircraft accidents and in-flight emergencies each year. One drastic example was the 1994 commuter aircraft crash in Roselawn, Indiana, which killed 68 people. Icing was directly responsible for this tragedy.

When ice forms on an aircraft, it distorts the aerodynamic shape of lifting surfaces, resulting in degraded, if not total loss of, aircraft control. Accurate icing forecasts are extremely important to each aircrew. This FYI is a refresher on icing and its effects on aviation, along with a review of icing analysis and forecasting techniques.

"Icing is responsible for numerous aircraft accidents and in-flight emergencies each year."

Impacts on Aircraft

Icing is a serious hazard for many types of aircraft. Light fixed-wing or rotary aircraft are especially susceptible because of their relatively slow cruising speeds and limited altitude range.

Fixed-wing aircraft react poorly during icing conditions. Icing adds weight, increases drag and stall speed, and decreases lift. In addition, control surfaces and landing gear may malfunction when coated by ice.

Icing's effects on helicopters are potentially more severe than fixed-wing aircraft because of the obvious physical differences. With enough ice, rotor assemblies can vibrate out of control. All aerodynamic effects are greatly exaggerated which makes control unpredictable.

General

Two basic conditions must be met for ice to form on an airframe in significant amounts. First, the aircraft surface temperature must be colder than 0°C. Second, supercooled water droplets, liquid water droplets at subfreezing temperatures, must be present. Water droplets in the free air, unlike bulk water, do not freeze at 0°C. Instead, the freezing temperature varies from an upper limit near –10°C to a lower limit near –40°C. In general, the possibility of icing must be anticipated in any flight through supercooled clouds or liquid precipitation at temperatures below freezing.

Definitions

Frost. Light, feathery deposit of ice crystals which usually forms on the upper surfaces of parked aircraft. In this respect, frost is deceptive as it affects the lift-drag ratio of an aircraft, which would be a definite hazard during takeoff. Frost can also form on aircraft in flight during descent from subfreezing air into a warmer moist layer below. However, this is generally considered harmless since it melts as the aircraft warms.

Rime. Rime ice is rough, milky and opaque, similar to ice which forms in a freezer. The granular texture exists because the ice forms when very small droplets freeze almost instantly upon striking the aircraft and trap air between the spherical drops.

Rime ice is most frequently associated with stratus clouds at temperatures between –8°C and –10°C, although it has been observed to form between –2°C and –30°C. In comparison to clear ice, rime ice is relatively easy to remove by conventional deicing methods.

Clear. Clear ice is glossy, clear or translucent and is formed by the relatively slow freezing of large supercooled droplets. The large droplets spread out over the airfoil before complete freezing and form a clear sheet of ice. Clear ice is formed in cumuliform clouds and is the result of larger drops that are usually between 0° and –16°C. Freezing precipitation also generates clear icing.

Mixed. A combination of rime and clear icing.

Evaporation. The physical process by which a liquid is transformed to a gas. In meteorology, evaporation usually is restricted in use to the change of water from liquid to gas. In the icing process, evaporation causes cooling of the liquid as latent heat is lost.

Sublimation. The transition of a substance from the vapor phase directly to the solid phase, or vice versa, without passing through an intermediate liquid phase.

Classifications

Trace

Icing becomes perceptible; accumulation rate is slightly greater than the sublimation rate. This is not usually considered hazardous unless it lasts longer than one hour.

Light

Rate of accumulation may create a problem if flight is prolonged in the situation (over one hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation.

Moderate

The rate of accumulation is such that even short encounters become potentially hazardous. Use of deicing/anti-icing equipment is necessary.

Severe

The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard or it may have a possible catastrophic affect on aircraft.

Synoptic-Scale

Seasonal

Icing may occur during any season of the year, but in temperate climates, such as in most of the United States and northern Europe, it is most frequent in winter. Frontal activity is also more frequent in winter, and the resulting cloud systems are more extensive.

Generally regions at higher latitudes, such as Canada and Alaska, have the most severe icing conditions in spring and fall. In winter, polar

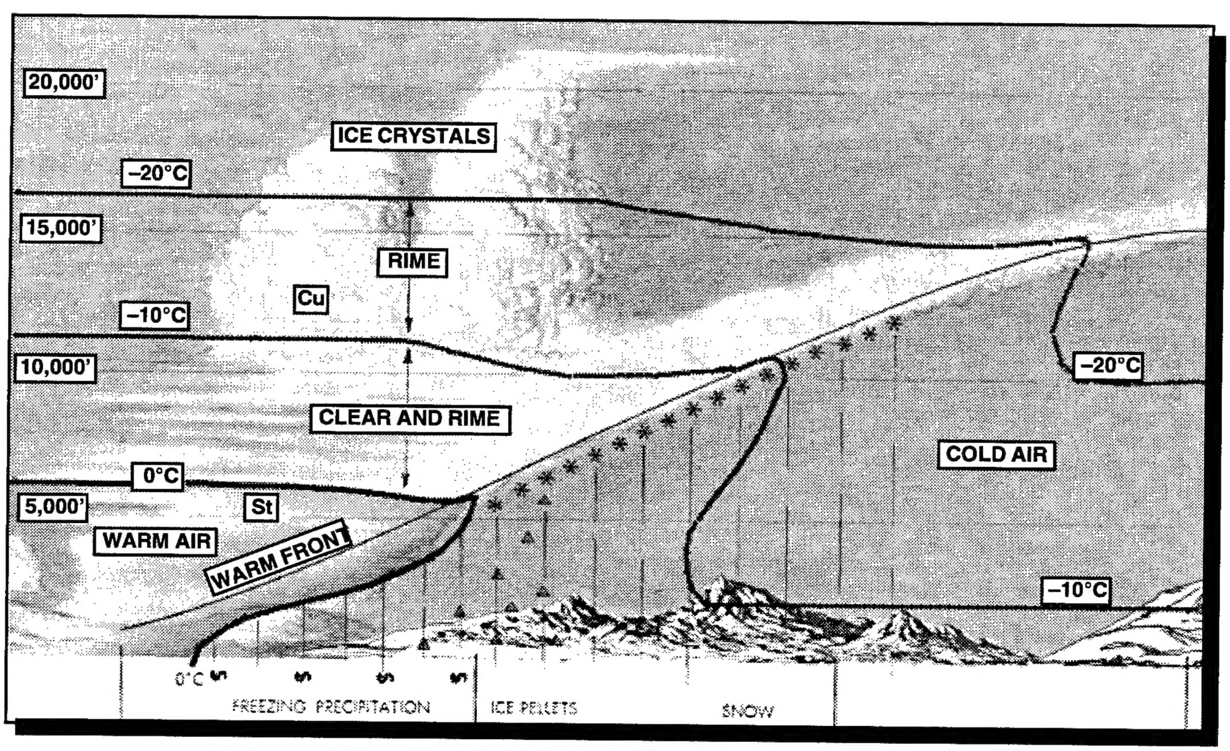

Figure 1. Icing Associated with Warm Fronts

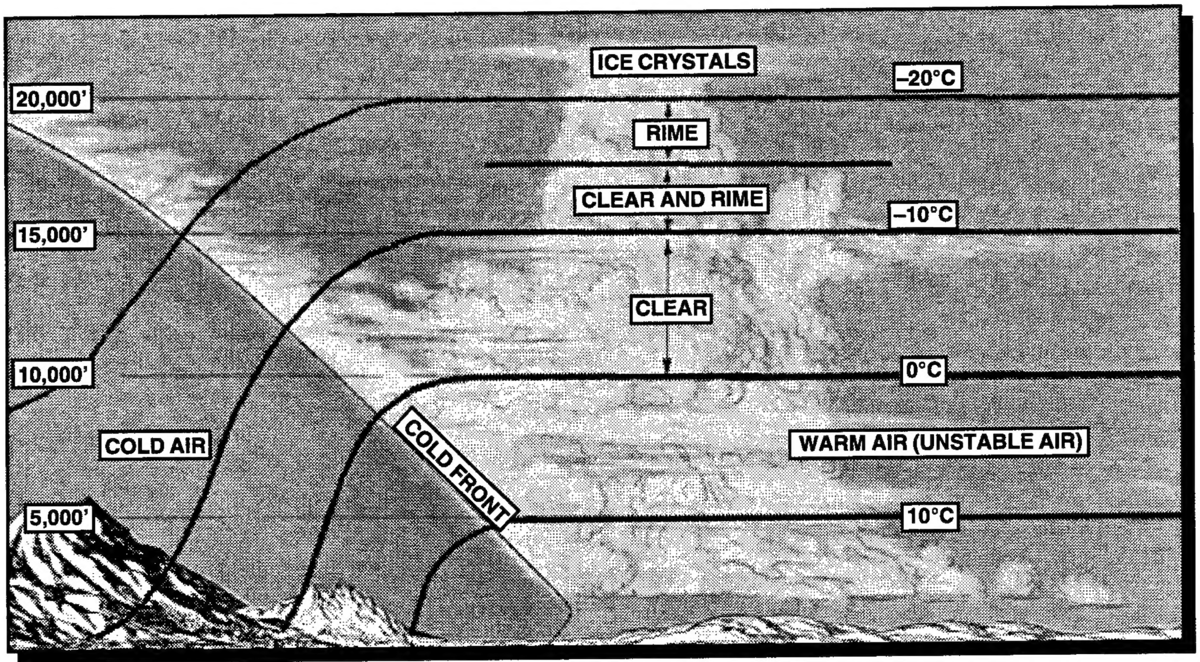

Figure 2. Icing Associated with Cold Fronts

regions are normally too cold to contain the concentration of moisture necessary for icing. Most cloud systems are stratiform and composed of ice crystals.

Frontal Systems

About 85 percent of all frontal icing conditions occur in the vicinity of frontal systems (see Figures 1 and 2).

For significant icing to occur above the frontal surface, the warm air must be lifted and cooled to saturation at temperatures below freezing, making it contain supercooled water. If the warm air is unstable, icing may be sporadic; if it is stable, icing may be continuous over an extended area. Icing may form in this manner over either a warm frontal or a shallow cold frontal surface. A line of showers or thunderstorms along a surface cold front may produce icing, but the icing will be in a relatively narrow band along the front.

Icing below a frontal surface outside of the clouds occurs most often in freezing rain or drizzle. Precipitation forms in the relatively warm air above the frontal surface at temperatures above freezing. It falls into the cold air below the front, becomes supercooled, and then freezes on impact with the aircraft. Freezing drizzle and rain occur with both warm fronts and shallow cold fronts.

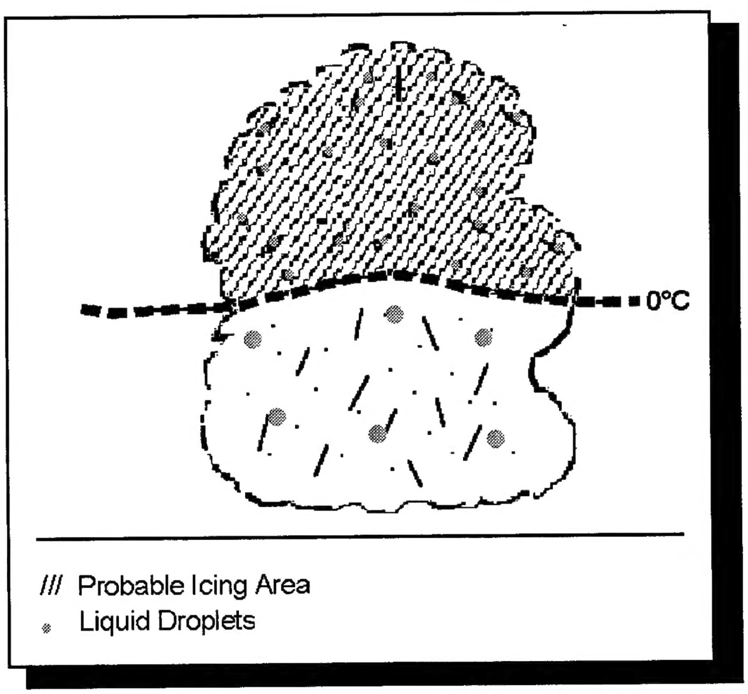

Figure 3. Icing Associated with Cumuliform Clouds

Cumuliform Clouds

The zone of probable icing in cumuliform clouds is smaller than in stratiform clouds (Figure 3). Icing is more variable in cumuliform clouds because many of the factors conducive for icing depend largely on the particular cloud's stage of development. Icing intensities may range from generally a trace in small supercooled cumulus to light or moderate in towering cumulus and cumulonimbus.

In a building cumulus icing occurs at all levels where supercooled droplets exist, but is most intense in the upper half of the cloud. The most severe icing occurs in towering cumulus clouds just prior to their change to cumulonimbus. Icing is generally restricted to the updraft regions in a mature cumulonimbus and to a shallow layer near the freezing level in a dissipating thunderstorm. Icing in cumuliform clouds is usually clear or mixed.

Thunderstorms

The most significant icing occurs in developing and mature thunderstorms (Figure 4), but little occurs in dissipating thunderstorms. This happens because the greatest icing areas are associated with strong updrafts: dissipating thunderstorms have mostly downdrafts.

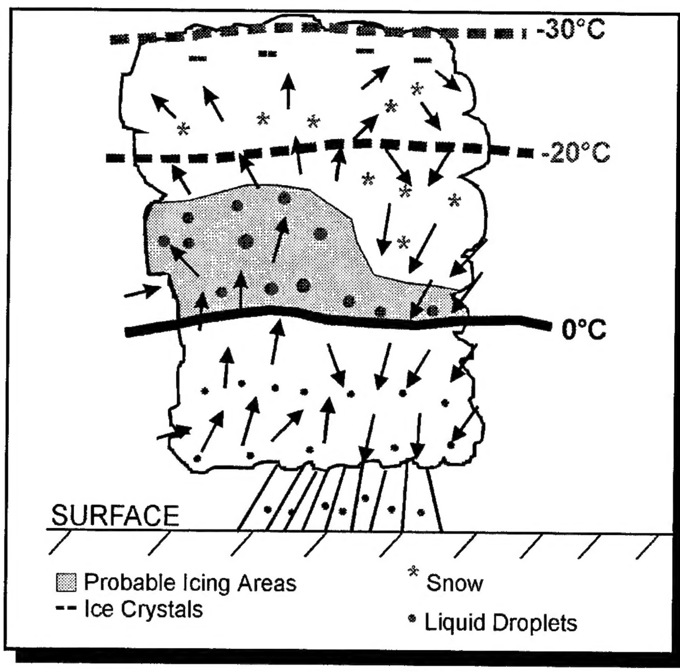

Figure 4. Icing Associated with Thunderstorms

Terrain

Icing is more likely and more severe in mountainous regions than over other terrain. Mountain ranges cause upward air motions on their windward side. These vertical currents support large water droplets aloft that would normally fall as rain over level terrain. The movement of a frontal system across a mountain range combines the normal frontal lift with the mountain's upslope effect to create extremely hazardous icing zones.

The –8D Method

One effective way to forecast icing is –8D Method on your Skew-T. Use the –8D Method (Figure 5) to identify areas favorable for icing.

In this example (Figure 6), the air in the middle layers is supersaturated with respect to ice. You would forecast icing in this layer using the figures and on the attachment to determine type and intensity.

Consider the following when using the –8D Method:

- When the dewpoint depression is 0°C, the –8D curve must fall along the 0°C isotherm. In a subfreezing layer, the air would be saturated with respect to water and supersaturated with respect to ice. Light rime icing would occur in altostratus or nimbostratus clouds in such a region, and moderate rime icing would occur in cumulonimbus, cumulus, and stratus.
- When the temperature and dewpoint do not coincide but the temperature curve lies to the left of the –8D curve in the subfreezing layer,

The –8D Method

Step 1. Plot the upper air data on a sounding using any Skew-T program your station has. AWDS can be used with this method, but other Skew-T programs are recommended because the data are easier to manipulate.

Step 2. Determine the dewpoint depression for the significant levels. This is called D and is always taken to be positive.

Step 3. Multiply the dewpoint depression (D) by –8 and plot the product (°C) at the appropriate pressure levels.

- Dewpoint depression (5°) x (–8) = –40

Step 4. Accomplish Step 3 for each temperature between 0° and –22°C.

Step 5. Connect the points plotted by Step 4 with a line.

Step 6. Icing layers are bounded by the intersection of the temperature and the –8D curve when the –8D curve is on the right. In this layer, supersaturation with respect to ice exists. These are the hatched areas shown in Figure 6.

Step 7. The cloud type and the precipitation observed at the raob time or the forecast time, as well as the temperature and dewpoint, may be used to determine the type and intensity of icing.

Figure 5. Calculating Icing Using the –8D Method

the layer is supersaturated with respect to ice and probably subsaturated with respect to cloud droplets. If the clouds in this layer are altostratus, altocumulus, or stratocumulus, only light rime icing will be encountered. If the clouds are cirrus, cirrocumulus, or cirrostratus, only light frost will be sublimated on aircraft. In cloudless regions, there will be no supercooled droplets, but frost will form on the aircraft through direct sublimation of water vapor. This is critical to aircraft and helicopters that can't tolerate any form of icing.

- When the temperature curve lies to the right of the –8D curve in a subfreezing layer, the layer is subsaturated with respect to both ice and water surface. No icing will occur in this region.

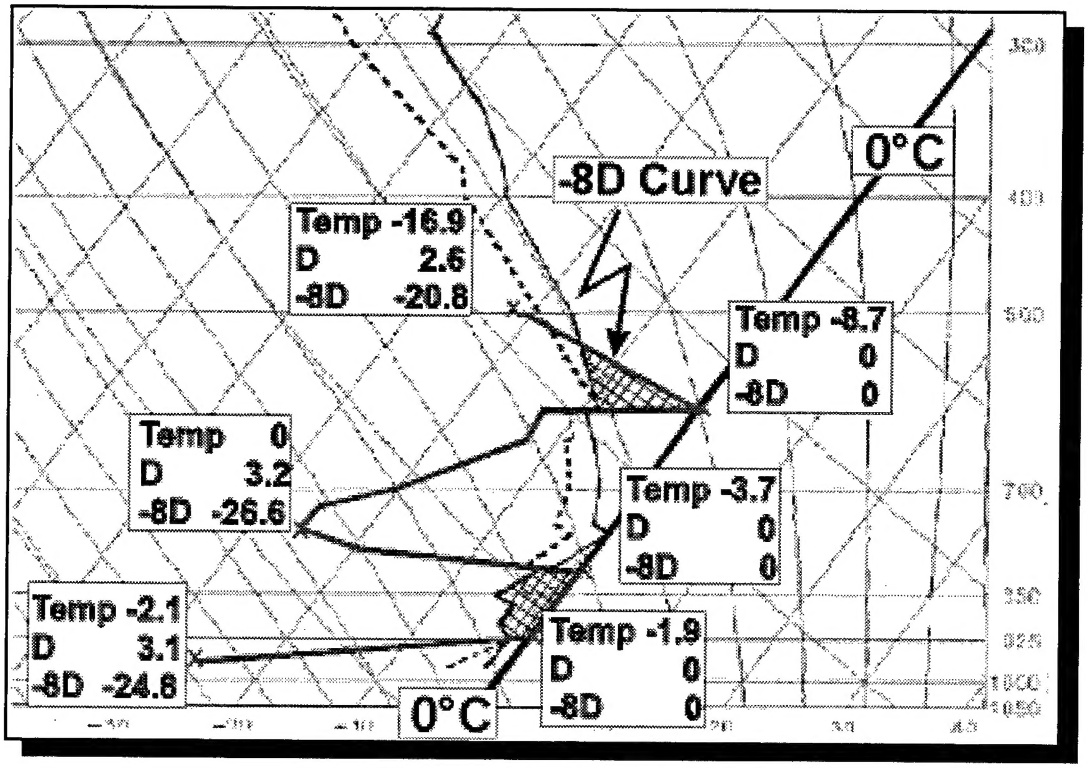

Figure 6. The –8D Method

☑ SATELLITE

Satellite imagery can help you detect potential areas of icing. There are five spectral channels on GOES-8 and GOES-9. Three channels (Channels 1, 2, and 4) can be useful in spotting potential aircraft icing zones.

Parameter	GOES Channel
Temperature (0 - 20°C)	Channel 4
High liquid water content	Channels 1 and 2
Large droplet diameters	Channel 2
Area coverage and thickness of clouds	Channel 1
Upward vertical velocity	Channel 1

Figure 7. GOES Channel Usage

Figure 7 shows meteorological conditions identified as important with icing in clouds and the GOES channel useful for their identification.

Visible imagery obtained from Channel 1 can be useful in several respects. Primarily, it can show the horizontal extent of clouds and a relative measure of cloud thickness and water content from the observed brightness of the cloud layers. It can also be used to identify areas of embedded convection.

Cloud top temperatures are available from infrared imagery on Channel 4. Icing may be present if the cloud top temperatures are within the favorable range of 0° to –20°C and no higher cloud cover exists.

During the daytime, liquid phase clouds look warmer (darker) than ice phase clouds in the shortwave infrared channel (Channel 2). Therefore, by comparing Channels 4 and 2 temperatures, you can find supercooled

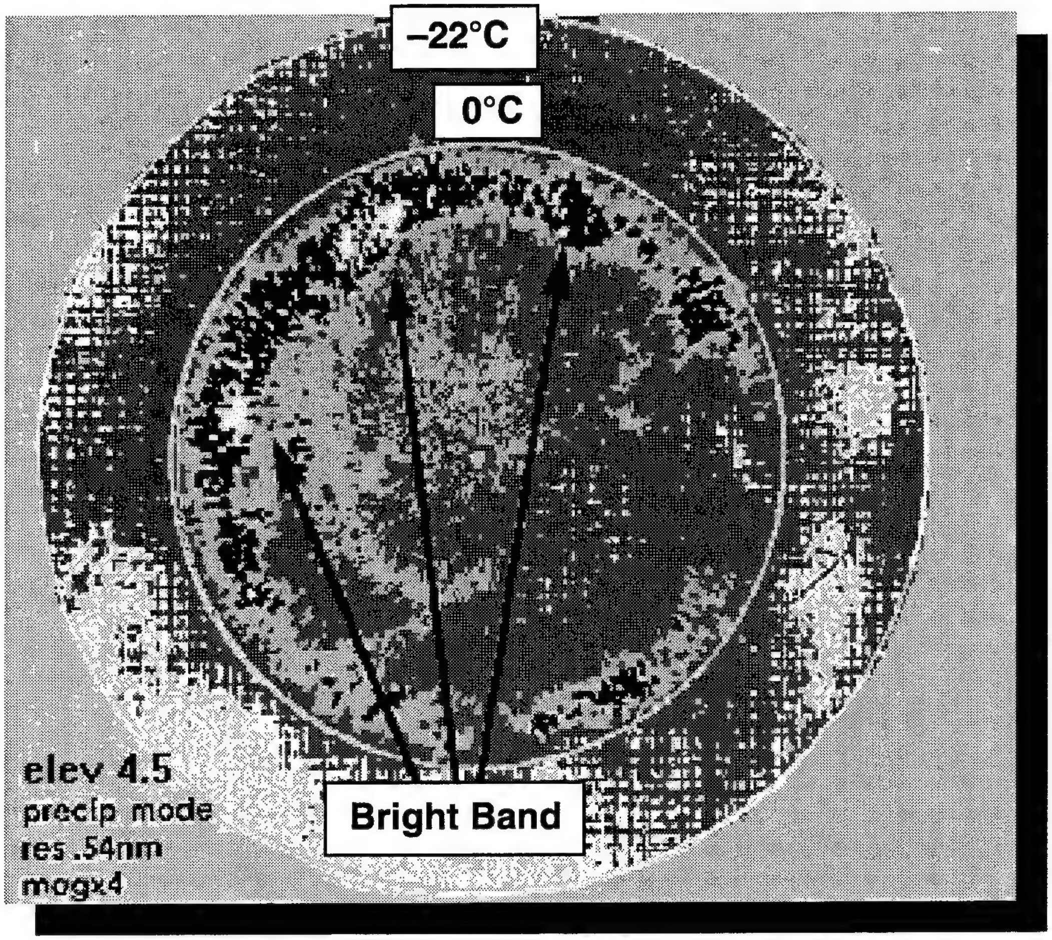

Figure 8. WSR-88D Bright Band

clouds. Embedded lighter gray shades sometimes associated with more intense icing are caused by larger cloud droplet sizes or slightly thicker clouds.

✓ RADAR

You can use radar to determine potential icing areas by looking at the reflectivity-based products. As ice crystals fall through the melting level, their outer surface begins to melt. Just below the melting level (0°C surface), large water-coated ice crystals are highly reflective. This high reflectivity produces enhanced radar signatures with a ring-like structure (Figure 8). This feature is called the "bright band" because of its appearance on conventional weather radars. This echo is interpreted as lying just below melting level.

Step 1: Find the 0°C isotherm or the freezing level by identifying the bright band.

- Seen as a ring of enhanced reflectivity (Normally found between 30-45 dBZ).
- The outer edge is the freezing level or 0°C level.
- The level can be determined by placing the cursor on the freezing level and reading the height.

Step 2: Use Skew-T data or PIREPS within the local area to determine the height of the –22°C isotherm.

- Use the cursor to locate this elevation on your reflectivity product.

Any returns present between the freezing level and the –22°C height have the potential to produce icing.

Note: The bright band can also be identified using a reflectivity cross-section.

ANALYSIS AND DISPLAY SYSTEMS

Generate a vertical cross section on AWDS using Uniform Gridded Data Field (UGDF) data to show the amount of moisture in the atmosphere and the associated temperature of the levels of interest. UGDF is model-based output data, so be sure to initialize and verify the model before using it. Formatted Binary Data (FBD) can be used as well, but UGDF has finer resolution and may pick up moisture pockets FBD may miss. Evaluate the cross section to see where rules of thumb apply (see Figures 9-10 and Pages A-1 to A-3). The important parameters and thresholds for your cross section (Figures 9 and 10) are:

- Relative humidity (RH) greater than 65 percent will highlight general, broad areas of icing.
- Investigate further by analyzing for dewpoint depressions of 2°, 3°, 4°, and 5°C.
- Use temperature values of 0°, –8°, –16°, and –22°C.

You can also forecast conditions moving into your area by setting your cross section points in an area upstream from your station. This allows you to get a slice of the atmosphere upstream. T-TWOS #12 lists procedures to develop an icing command sequence which generates this vertical cross section on AWDS.

WHAT'S NEW IN ICING RESEARCH

After the fatal crash in Indiana, prominent scientists from around the world investigated the weather associated with the disaster. They discovered a new type of icing that doesn't quite fall into the normal categories. Supercooled Large Water Droplets (SLD) are now the subject of intense studies within private industries, the Department of Transportation, and the Department of Commerce.

Previous drop diameters considered by aircraft manufacturers for icing detection and removal systems assumed the average drop in the icing environment was no more than 50 microns. SLD can reach a diameter of 400 microns and some aircraft, particularly smaller planes, cannot clear the icing as fast as it forms.

The environment which supports this severe icing is characterized by high liquid water content and "warm" supercooled temperatures between 0° and –8°C. Vertical wind shear also plays a part in SLD development, but a primary indicator is the presence of freezing drizzle or freezing rain at the surface. The National Center for Atmospheric Research discovered a close correlation with freezing precipitation at the surface and SLD development aloft. This is factored into their stovepipe algorithm which is used to forecast this deadly type of icing.

Research continues in this field and new models are being developed that can detect the potential for SLD. Currently, forecasting techniques are not developed for use at the local level. However, the Aviation Weather Center in Kansas City, Missouri, produces AIRMETS and SIGMETS specifically tailored to pinpoint locations where SLD are likely. We recommend you add these bulletins to your data requirements, especially if you support medium- to small-size aircraft.

A recent study conducted by icing experts at the National Center of Atmospheric Research (NCAR) discovered relationships between in-flight aircraft icing and synoptic-scale weather phenomena. They examined 37 wintertime and fall weather systems, and concluded the four criteria listed below were the situations most likely to support icing conditions.

- Airmasses.
  - **Arctic**: Of Polar/Canadian origin, temperatures less than 10°C, and northerly winds.
  - **East Coast**: Originates in the Atlantic, usually remains east of the Appalachians, and easterly winds.
  - **West Coast**: Originates in the Pacific, normally remains west of the first range of mountain, and westerly winds.
- From 90 to 370 miles ahead of active and quasi-stationary warm fronts.
- Within freezing precipitation areas.
- Within obscured and overcast sky conditions when precipitation was not occurring.

NCAR is still finalizing the results of the study. Final results will be published in a future edition of *Weather and Forecasting* magazine, published by the American Meteorological Society.

SUMMARY

As you can see, there are many variables and tools to consider when evaluating occurrence, type, severity and levels for aircraft icing. It's worth the trouble because your forecast will be critical for aircrews using ***your*** forecast.

"Accurate icing forecasting is extremely important to each aircrew . . . . It's important you understand how icing affects your customer and their aircraft."

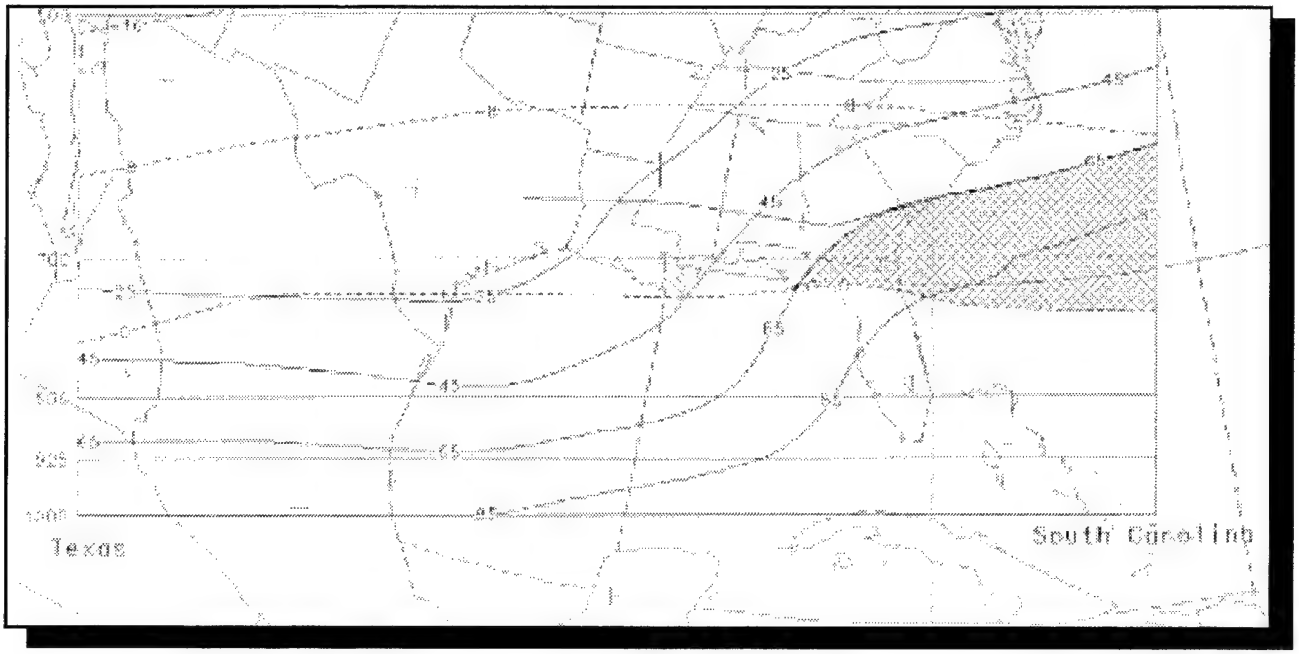

Figure 9. AWDS Temp/RH Vertical Cross Section
Areas with RH Greater than 65 Percent and Temps Between 0°C and -8°C Highlighted

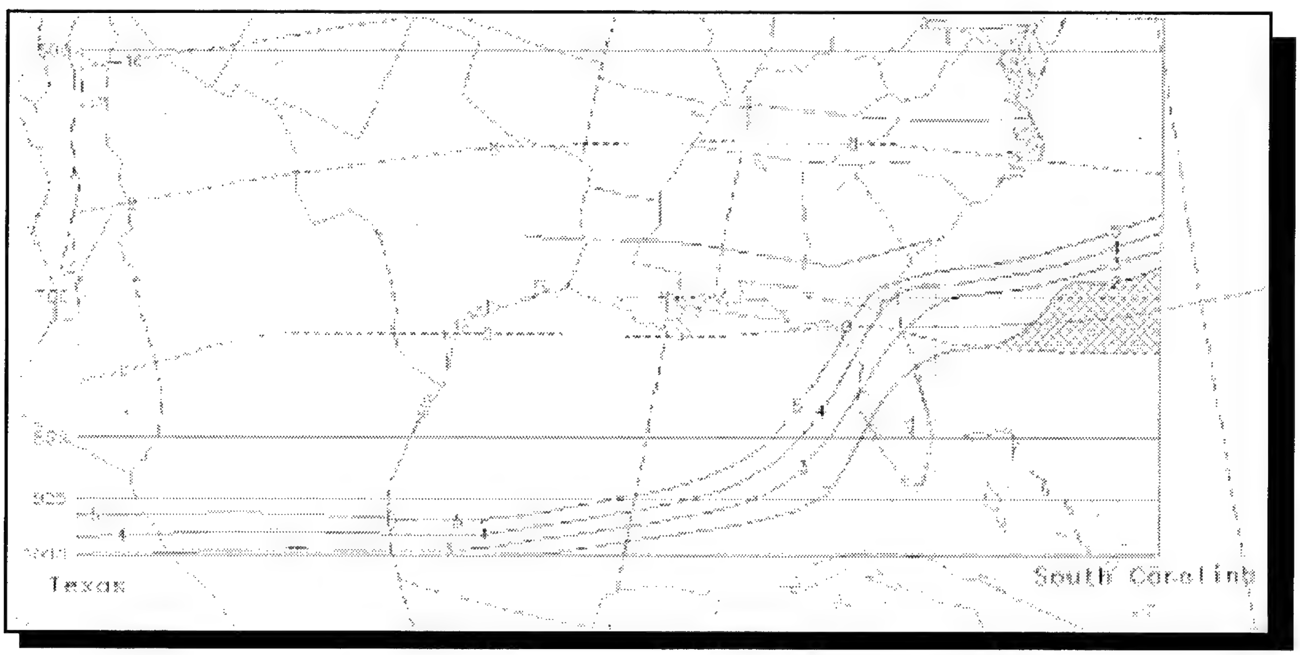

Figure 10. AWDS Temp/Dewpoint Depression Vertical Cross Section
Areas with Dewpoint Depression within 2°C and Temperature Less than 0°C Highlighted

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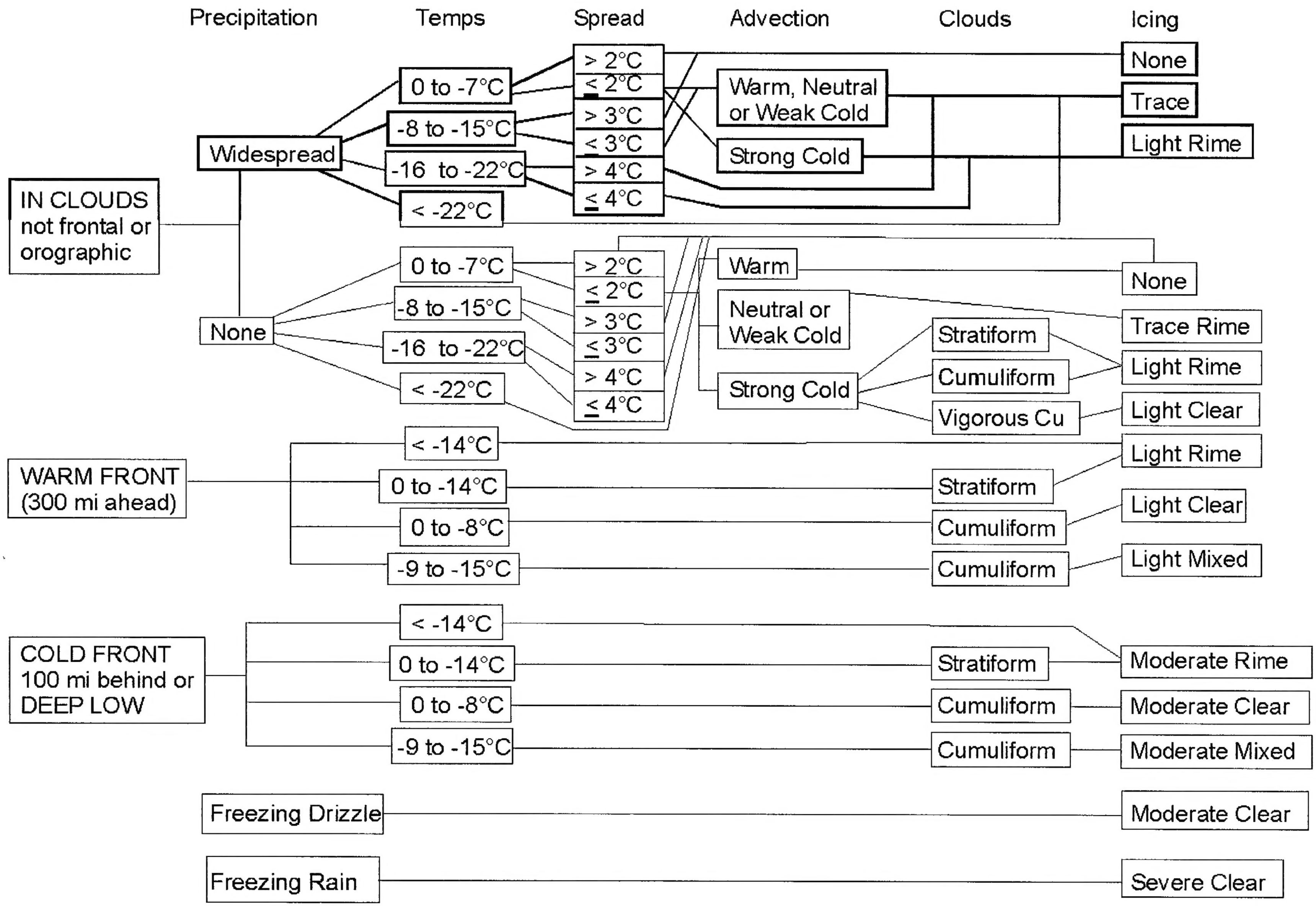
✓ Icing Flowchart



TABLES

Figure A-1 helps you forecast the icing type based on temperatures and cloud type.

Temperature	At or In	Icing Type Forecast
Below -15°C	Flight Level	Rime
0°C to -15°C	Stable Stratiform Clouds	Rime
0°C to -8°C	Cumuliform Clouds and in Freezing Precipitation	Clear
-9°C to 15°C	Cumuliform Clouds	Mixed (Rime and Clear)

Figure A-1. Icing Type Forecasting

Use Figure A-2 for a general assessment of icing probability.

80 Percent Probability of No Icing	
Temperature	**Dewpoint Depression**
0°C to -7°C	> 2°C
-8°C to -15°C	> 3°C
-16°C to -22°C	> 4°C
Lower than -22°C	> 5°C

Figure A-2. When to Forecast No Icing

Figure A-3 breaks the probability of icing down based on temperature, moisture, and advection parameters.

Temperature	Dewpoint Depression	Advection	Forecast	Probability
0°C to -7°C	≤ 2°C	Neutral/Weak Cold Air	Trace	75%
		Strong Cold Air	Light	80%
-8°C to -15°C	< 3°C	Neutral/Weak Cold Air	Trace	75%
		Strong Cold Air	Light	80%
0°C to -7°C or -8°C to -15°C	≤ 2°C or < 3°C	None Associated areas with vigorous Cu buildups due to surface heating	Light	90%

Figure A-3. Icing Intensity Guidance

Use Figure A-4 to determine icing intensity based on the weather system affecting your area.

Description	Position of Clouds	Icing Forecast
Not Due to Frontal Activity or Orographic Lifting	Over Areas with Steady Liquid Precipitation	Little or None
	Over Areas with No Liquid Precipitation	Light
Due to Frontal Activity or Orographic Lifting	Presence/Absence of Precipitation is not an Indicator	Indeterminate
Up to 300 miles ahead of Warm Frontal Surface Position		Light
Up to 100 miles ahead of Warm Frontal Surface Position		Moderate
Over Deep, Almost Vertical Low Pressure Center		Moderate
In Freezing Drizzle (In or Below Clouds)		Moderate
In Freezing Rain (In or Below Clouds)		**Severe**

Figure A-4. Icing Intensity Guidelines

FYIs

FYI #9:	MOS Guidance	Nov 92
FYI #10:	Technical Improvement	Nov 92
FYI #11:	Commanders WX Info Pamphlet	Nov 92
FYI #12:	TAFVER	Nov 92
FYI #14:	Fixed Meteorological Equipment	Feb 93
FYI #16:	RVR-2	Feb 93
FYI #17:	Lightning Detection System	Feb 93
FYI #21:	Medium-Range Forecast (MRF) Based Objective Forecast Message (OFM)	Jul 93
FYI #22:	TAFVER II Statistical Output	Sep 93
FYI #23:	Conditional Climatology (CC) Tables	Sep 93
FYI #24:	A Layman's Guide To Developing A Forecast Study	Jan 94
FYI #27:	Weather Staff Officer's Guide To Climatology	Mar 94
FYI #29:	SHARP	Aug 94
FYI #30:	Air Force Weather Bulletin Board	Aug 95
FYI #32:	Freezing Drizzle	Feb 96
FYI #33:	Turbulence	Apr 96
FYI #34:	Continuation Training	Jul 96
FYI #35:	Metsat Program	Aug 96
FYI #36:	Forecast Discussion Bulletins	Dec 96
FYI #37:	Space Environmental Impacts on DoD Operations	Feb 97
FYI #38:	Icing	Mar 97